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Rock Mechanic Application for Future Heavy Oil Development, Shallower Reservoir and Highly Faulted Area: A Geomechanical Model for Central Sumatra Oil Field

Fitra Adlan[a,]a*

[a] *Institute Technology Bandung, Bandung 40191, Indonesia*

Abstract

Rock mechanic study become an important tools for future development in heavy oil. Steam injection at shallower reservoir and highly faulted area need more accurate risk assesment and calculate limit of steam injection. The information contained in a geomechanical model will give the alternatif for development scenario and increasing project economic.
Utilizing pore pressure, rock properties and stress model information can provide recommendations for efficient well design and placement to reduce drilling problem such as stuck pipe and lost circulation. A geomechanical model also makes it possible to designs completion to avoid or manage solids production. In addition, the effects of reservoir injection can be predicted to enable avoid hazards related to leakage of produce fluid or injected steam.
This paper will illustrate the prediction of fracture pressure related to seal or cap rock above shallower reservoir that will be injected by the steam, determining the apropriate mud window to control wellbore stability where te borehole has intersected critically stressed natural fractures or fault at faulted area that are related to high fracture permeability, calculate the upper bound pressure within the fault that could lead to escape of injected steam and calculate the minimum rock strength to prevent rock production.

1. Introduction

Central Sumatra Basin is the richest petroleum basin that produced oil in Indonesia. Almost fifty percent of oil in Indonesia produced from this basin. One of the oil field in this area produced more than 150,000 bopd. This oil field characterized by heavy oil and shallower reservoir. Oil could be found at 140 feet depth. Steam injection is a strategy used to reduce oil viscosity and increase oil production in this field. Injection fluid at shallower depth has a significant risk to create fracture to the surface and contaminate surface area with oil. This oil field not only has a shallower reservoir, but also located at highly faulted structure. This fault increasing the injection risk and should be maintain to avoid the fault to slip. Rock mechanic, an integration study of pore pressure, stresses and rock

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx .

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properties, was applied to calculate fault stability, cap rock fracture pressure, maximum injection pressure and recommended mud weight used to reduce drilling problem and maintain wellbore stability during drilling.

2. Stress Orientation and Magnitude

2.1. Constraining Stress Orientation

The orientation of the maximum horizontal stress defined from observation of drilling induced tensile fractures and the minimum horizontal stress from borehole breakouts which detected form borehole image. The orientation of maximum horizontal stress in this field is approximately N4ºE and minimum horizontal stress is N94ºE (Figure 1).

2.2. Stress Magnitudes

Vertical Stress

The vertical stress, S_v, is usually assumed to be equivalent to the weight of the overburden, that is,

$$Sv = \int \rho g h \tag{1}$$

Where ρ is the average mass density of the overlaying rock, g is the acceleration due to gravity, and h is the depth. If the density varies with depth, the vertical stress is determined by integrating the density of overlaying rocks. The average vertical stress gradient is approximately 0.85 psi/ft at the reservoir level.

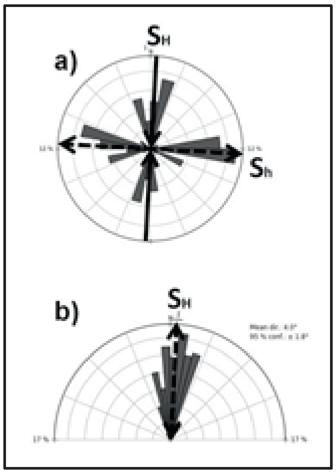

Figure 1. a) Orientation of SH danSh observed from borehole image, b) Orientation of SH from Breakout and DIF.

Minimum horizontal stress

The minimum horizontal stress (S_h) was determined from minifracs and extended leak of tests. Analysis of extended leak of tests at shale show fracture gradient of 0.71 psi/ft.

Analysis of minifracs indicate a wide range S_h. These S_h range from 0.47 psi/ft to 0.83 psi/ft. The non-uniformity of the S_h estimates in the sand units is most likely influence by steam injection. This field has spatially and temporally varying degrees of steam injection.

Maximum horizontal stress

To constrain the maximum horizontal stress (S_H), stress polygon plotting S_H versus S_h magnitudes were constructed at a single depth (Figure 2). A stress polygon illustrates all possible in situ stress states. The parameter of the polygon indicates the limiting values of S_h and S_H for which the state of stress is in equilibrium with the frictional strength of pre-existing faults, as predicted by Coulomb Faulting Theory. Stress states within the polygon correspond to normal faulting (NF: $S_v>S_H>S_h$), strike-slip faulting (SS: $S_H>S_v>S_h$), or reverse faulting (RF: $S_H>S_h>S_v$) stress states in which the ratio of shear to effective normal stress on any arbitrarily oriented fault is less than the coefficient of sliding friction (commonly 0.6–1.0). Furthermore, to constrain a stress state consistent with in situ conditions and observations of wellbore failures, the stress polygon is constructed for the mud weights used during drilling and the observed Pp conditions. Finally, contour lines of rock strength are superimposed on the stress polygon to take into account the occurrence (or absence) of wellbore breakouts. The strength values plotted on the contour lines reflect the UCS values from the strength log at a depth for which the stress polygon was constructed. This approach was described in detail by Peska and Zoback (1995).

3. Wellbore Stability Modelling

A common problem encountered during drilling occurs because mechanical instability at the borehole wall where stress amplification has exceeded the strength of the rock. Stress amplification on the rock surrounding the borehole wall is natural consequence of removing material that supported the insitu stress. The practical consequences of wellbore stability are often the borehole shear failure, manifested by the collapse of the borehole wall. Symptoms of borehole collapse are poor cementing, difficulties with logging response and log interpretation, and poor directional control. Lost circulation is another mechanical problem which in many cases is not related to mud weight exceeding the fracture gradient, but is related to a borehole that has encountered critically-stressed natural fractures/fault associated with high fracture permeability.

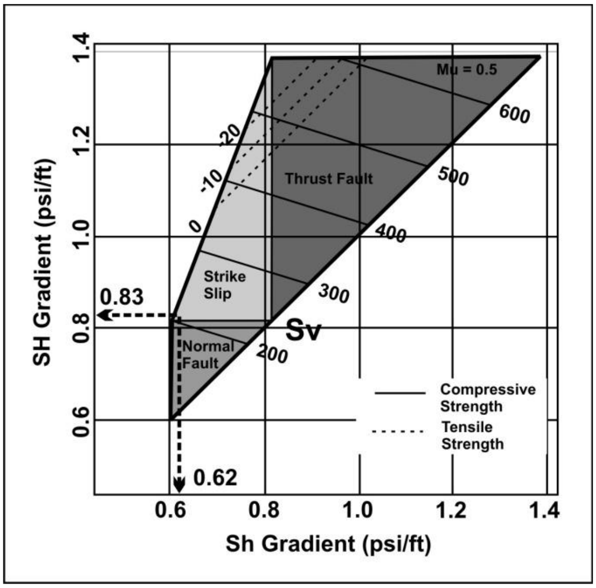

Figure 2.Polygon showing possible stress states at depth. The heavy dashed lines show the magnitude of SH (for a given value SH) that is required to cause breakouts with a width 70º for the rock strengths shown.

The shear borehole failure could be predicted by adopting compressive failure analysis in conjunction with a constitutive model for the stress around the borehole. The most commonly used failure criteria in wellbore stability analysis are the Mohr Coulomb Criterion. The Mohr Coulomb criterion involves only the maximum and minimum principal stresses, S1 and S3. It implicitly assumes that the intermediate principal stress, S2, has no influence on rock strength. These stresses should be compared with a failure criterion in order to determine the minimum mud pressure required to prevent borehole collapse.

With the stress tensor-well constrained (SH, Sh, Sv and SH stress direction), it is then possible to determine the appropriate degree of overbalance or mud weight required to stabilize the borehole for any arbitrary trajectory. In this case, we set UCS = 200 psi. Results shown in Figure 3 are displayed in a lower hemisphere stereographic projection with vertical boreholes located in the centre of the plot and arbitrary inclined holes shown as a function of azimuth and inclination. A near vertical well or one drilled in the Sh direction requires the most aggressive use of elevated mud weight. In contrast, a near horizontal wells within SH stress direction not require higher mud weight.

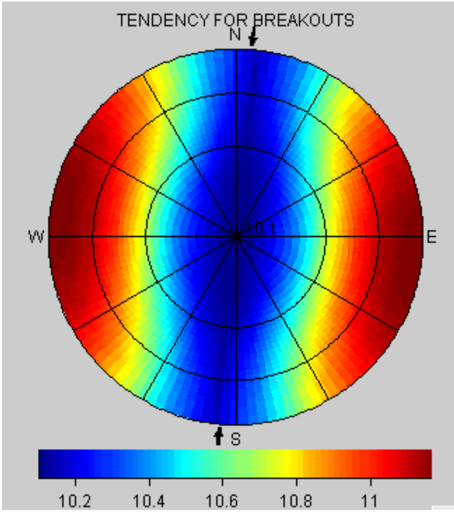

Figure 3 shows the mud weight required to achieve an acceptable level of wellbore stability as a function of well trajectory. Wells drilled in a westerly or easterly direction with deviation angles greater than 30□ □ will need higher mud weight to maintain wellbore stability. For nearly vertical wells (points near the centre of the plot) a lower mud weight is required.

4. Mitigation Injection Risk

Fault integrity evaluated by investigating the potential for fault reactivation through either hydraulic fracture or shear failure mechanisms. A number of studies have shown that shear failure along faults can increase fault permeability and compromise reservoir trap integrity. The orientation of a fault, and the magnitudes of the present-day stresses and pore pressure acting on the fault, will determine whether the fault has the potential for shear failure or hydraulic fracture. To evaluate the relationship between fault integrity and the present stress state in this field, it is important that the fault geometries and geomechanical model be well constrained.

Coulomb frictional failure is defined in equation 3, where τ is the shear stress, σ_n is the effective normal stress ($\sigma_n = S_n - P_p$, where S_n is the normal stress), and μ is the coefficient of sliding friction (Jaeger and Cook, 1979).

$$\tau = \mu \sigma_n \tag{2}$$

The Coulomb failure criterion states that a fault element is critically stressed (i.e., expected to slip) when CFF is positive (Equation 4).

$$CFF = \tau - \mu(S_n - P_p) \geq 0 \tag{3}$$

The Coulomb failure criterion can also be solved for the pore pressure (called the critical pore pressure, Ppcrit) at which a fault element will begin to slip (Equation 5).

$$Pp_{crit} = S_n - \tau/\mu \tag{4}$$

We calculate Ppcrit and CFF utilizing a coefficient of sliding friction of 0.5. It is possible to hydraulically fracture faults that are sub-parallel to the SH stress direction if a pressure entering the fault exceeds the normal stress (Equation 3).

$$\sigma_n = S_n - P_p \leq 0 \tag{5}$$

Figure 4a and 4b show view of the fault where the critical pressure difference for each of two stress scenarios (un-steamed area and mature steam flood area) colors each fault surface. Figure 4a shows that under depleted stress condition the deeper reservoir are not in critically stress condition. The shallowest portion of the fault has the greatest likelihood of shear failure in the current stress field. Figure 4b shows that faults are at high risk of leakage.

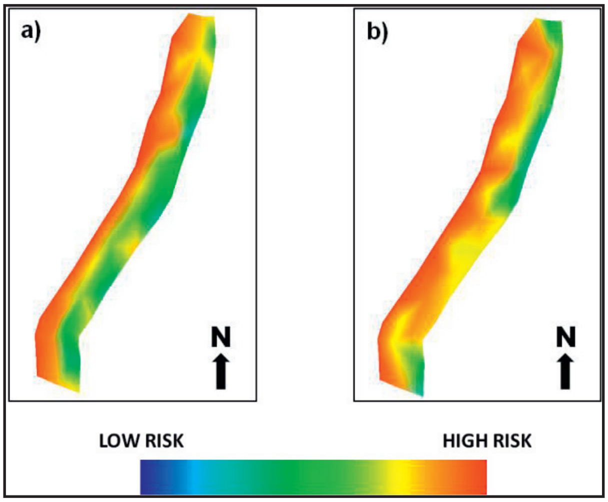

Figure 4. Fault surface are colored to show the critical pressure difference, bright red correspond to conditions in which faults are active whereas blue corresponds to stable fault.

Maximum injection pressure was assigned by combining Ppcrit and fracture pressure at cap rock above the reservoir. The lowest value from both calculation used as upper limit of injection pressure.

5. Conclusion

Application of rock mechanic could be used as risk assessment tool to mitigate risk at shallow and faulted reservoir. Estimation of mud weight used and more stable well direction could reduce operational cost in this area. Calculation maximum injection risk at this area also optimize steam injection and maximize oil production in this field.

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